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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

IODINE LASER

by

William Harry Halliday

June 1977

Thesis Advisor: F. R. Schwirzke

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IODINE LASER

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN PHYSICS

from the

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June 1977

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ABSTRACT

There has been a project at the Naval Postgraduate School for the past two years to build a high power, short pulse, Iodine Photodissociation Laser to be used for plasma and nuclear fusion related research. The first attempt, reported previously, met with difficulties. This paper details the changes made to the previous system in order to achieve a working laser. Lasing was observed for the first time on 31 January 1977. First shot energies up to 150 millijoules have been obtained in a pulse length of 15 microseconds. Investigation was carried out on the reduction in output energy with repeated shots on the same gas filling. The rate of deterioration was shown to increase with increasing fill pressure and to be caused mainly by the formation of molecular iodine. Removal of the molecular iodine between shots significantly reduced the deterioration rate.

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The people who have contributed ideas, time, effort, and equipment to this project are too numerous to list completely. Special thanks are in order to Mr. Robert Sanders for his technical and logistical help; Mr. Tom Maris for the hours spent coating mirrors; Prof G. Crittenden for the InSb IR Detector; LCDR Jim Polk, my lab partner, for his patience and helpful suggestions; and to MR1 Travis Adams of the NPS macine facility for his excellent machining of many parts of the laser, in particular, the extremely difficult double ellipscidal reflector.

Very special thanks goes to Professor Fred Schwirzke for his assistance, encouragement and guidance in producing this work.

I. INTRODUCTION

There has been a project at the Naval Postgraduate School for the past two years to build a high energy, very short pulse Iodine Photodissociation Laser. The laser will be used as a research tool for the creation of plasmas from very short, high energy pulses which is of current interest in the nuclear fusion program.

The first phase of this project was the design and construction of an Iodine Photodissociation Laser Oscillator stage. The intial design and construction was carried out by F.C. Marcell, Jr. as his M.S. thesis topic. The object of his thesis was to construct a laser that could be used as the oscillator stage of a multistage Iodine Laser. It was envisaged that another thesis student would construct the first amplifier stage and interconnecting optics as a thesis project. This plan had to be modified because the progress of the construction of the laser oscillator was impeded by some major problems. There proved to be insufficient time available to overcome all of these problems. The status of the design and construction of the oscillator stage to June 1976 is reported by Marcell[1].

This report details the changes made to the mechanical, electrical and optical systems as they were previously reported[1]. These changes were made throughout a six month period with attempts made to achieve lasing after a significant component was modified. The major components modified were the capacitor charge and discharge system, the gas handling system, the laser tube and flash assembly, and the optical resonator. Figures 1 and 2 are reproductions of

oscilloscope traces of typical output pulses without a buffer gas added. Lasing was observed for the first time on the 31 January 1977.

This paper also reports on the output characteristics of the NPS Iodine Laser detailing the variation of output energy with the pressure of C_3F_7I gas and Argon buffer gas.

The appendices to this report contain an operations manual for the Iodine Laser. They outline all the procedures to correctly perform an alignment of the laser, to do a purification cycle on the iodine gas, to fill the laser tube, to fire the laser and, to properly secure the laser.

II. BACKGROUND

The first photodissociation Iodine Laser was developed in 1964 at University of California, Berkley, by Kasper and Pimental[2]. The Iodine Laser has undergone intensive study towards the production of very high energy, extremely short pulses(<1ns) for laser fusion research. The Iodine Laser uses either trifluoromethyliodide CF_3I or perfluoropropyliodide C_3F_7I with a buffer gas such as argon or helium. The laser oscillator constructed at NPS uses C_3F_7I with argon as the buffer.

The C_3F_7I molecule is photodissociated by the ultraviolet radiation from a pair of pulsed xenon filled flashlamps. The absorption spectra, Figure 3, of the organic iodine molecules shows a peak centered near 2700 angstroms with a width of about 400 angstroms. The maximum cross section is about 6×10^{-19} cm^2. The photodissociation reaction is described by the following equation.

$$C_3F_7I + h\nu_{uv} = C_3F_7 + I(^2P_{1/2})$$

Lasing action at 1.3152 micrometers[3] comes from the forbidden dipole transition which is described by the following equation.

$$I(^2P_{1/2}) = I(^2P_{3/2}) + h\nu_{laser}$$

In additicn to these two reactions there is also collisional deactivation according to the following equation -

$$I(^2P_{1/2}) + C_3F_7I = I(^2P_{3/2}) + C_3F_7I$$

which leads with further collisions to the formaticn of molecular iodine according to the following equation.

$$2I(^2P_{3/2}) + C_3F_7I = I_2 + C_3F_7I$$

The formation of molecular iodine is of particular importance here because of its deleterious effects upon the laser performance. Molecular I_2 has a high rate constant for collisicnal deactiviation[4] and therefcre can readily quench laser cscillaticn. The oxygen molecule also has a high rate constant, therefore care must be taken to ensure that the system has as low a leak rate as possible.

Recombination, which is beneficial, also takes place according to the fcllowing equation.

$$I(^2P_{3/2}) + C_3F_7 = C_3F_7I$$

The excited iodine has a lifetime of 130 msec[5] which means that large population inversions can be obtained, consequently the potential exists for high power outputs. In crder to develop this high power in a short pulse, the emission crcss section must be low enough to prevent spcntaneous laser acticn.

One method of obtaining a lower cross section is the addition of inert gases to the lasing medium[6]. According to Aldridge:

> "Inert gas pressure broadening of the iodine laser emission line is thus as effective as magnetic broadening in reducing the emission cross section and increasing the energy storage capacity of this laser system......[6]"

Aldridge[6] goes on to point out that inert gas pressure broadening is a homogeneous mechanism, whereas the magnetic field broadening is inhomogeneous. The NPS Laser has the capability of inert gas pressure broadening using argon as the medium.

III. DESIGN AND CONSTRUCTION

All following references to changes, modifications or other words to that effect, are made using the Iodine Laser reported by Marcell[1] as the basis.

A. CAPACITOR CHARGE AND DISCHARGE SYSTEM

In an effort to increase the pumping energy to the flashlamps as recommended[1], the entire capacitor discharge system was rebuilt. The 1.5 microfarad capacitor was replaced with two 7 microfarad (nominal) 25KV capacitors connected in parallel. This increased the energy storage capacity of the system by a factor of ten. RG-58/U cabling was used for all wiring external to the aluminum mesh cage constructed around the capacitor/spark gap system.

The higher capacitance of the new system resulted in an increase in the charging time to an unacceptable length. The series resistor in the charging line was changed from 9 megohm to 3 megohm, reducing the time constant of the circuit from 126 seconds to 42 seconds. The dump time proved to be the same as the charge time via the same resistor. The interconnections of relays K8 and K9 were changed and a 100K resistor added. When the dump is activated, either directly or by the firing switch, Figure 4, the main capacitor bank is connected to ground through the 100K resistor. This permits a dump time of less than 1 second. The schematic of the charge, discharge and dump circuitry is shown in Figure 5. The four element spark gap

was modified slightly by the addition of a screwdriver through the plexiglass wall with appropriate seals to permit pressurization. The screwdriver allows adjustment of the gap in the tungsten trigger electrodes with out completely dismantling the spark gap. This modification proved very useful. Note warning in adjustment procedures in Appendix D, Item 4. A system layout diagram is shown in Figure 6.

B. THE GAS HANDLING SYSTEM

As reported in Ref. 6, oxygen molecules can readily quench laser operation. In order to be assured that this was not the factor that was preventing lasing, the entire vacuum system was repackaged. A schematical layout of the new gas/vacuum system is shown in Figure 6. All vacumm lines were shortened as much as physically possible, with some valves and lines being deleted. The system base pressure was improved by an order of magnitude to 10^{-6} Torr.

C. THE LASER TUBE AND FLASH ASSEMBLY

The flashlamps provide an arc length of 45.68 cm. The former system used 26 cm of this length (57%) which meant that 43% of the flashlamp energy was not being used. The length of the laser tube was increased to utilize more of the arc length available from the flashlamps. The present system uses 40.8 cm of the useable arc length (89.3%). The increase in length of the laser tube required considerable reorientation of the components and modifications to the flashlamp holders. The reflector was lengthened by the addition of an identically machined extension.

The laser tube was changed from a 5 mm inside diameter to a 10 mm inside diameter Suprasil quartz tube. This change required remachining of the monel laser head assemblies to accept the larger tubing.

D. OPTICAL CAVITY

The optical cavity was modified after lasing had been achieved. The modifications were done in order to create more room for the planned Pockel's Cell Q-Switch. It was felt that moving the present mirrors further apart would be detrimental to the laser operating in the TEM_{00} mode. A hemiconfocal resonant cavity is conducive to TEM_{00} and by adjusting the cavity length the TEM_{00} mode can be made certain[7]. The existing system was already 14% longer than the focal length. The 1.52 meter spherical mirror was replaced with a 2 meter mirror and the cavity adjusted to 1 meter.

It was noted during the further firings of the laser to investigate the output mode, that the output mirror coating was being destroyed. The mirror coating was a vacuum deposited gold layer with a silicon monoxide protective coating. The transmittance of the mirror was checked on a spectrophotometer to be 80% at 1.315 micrometer wavelength. It was assumed at this point in the investigations, that the absorption by the mirror was negligible and that the reflectivity of the mirror was approximately 20%. This proved to be an invalid assumption.

A series of tests with gold coated mirrors was run checking the first shot output energy versus transmittance.

The results, Figure 8, tend to indicate that a transmittance of 50% is near optimum.

During these tests, the gold coating on the mirrors was destroyed in varying amounts. In an effort to overcome this problem, a 100% reflecting dielectric film mirror from a 1.06 micrometer wavelength Nd glass laser was tested and found to have a transmittance of 80% at 1.315 micrometer wavelength. The absorption by dielectric films is much less than deposited metal films[8], therefore it is a reasonable assumption that this mirror has approximately a 20% reflectivity. A repeatable first shot energy of 150 millijoules was obtained with this mirror. A similar mirror with a 93% transmittance was tried and yielded 80 millijoules first shot energy. As an endpoint check, the laser was tried without an output mirror and a repeatable first shot energy of 10 millijoules obtained. These last three data points indicate that vacuum deposited gold film mirrors produced at NPS are not satisfactory for use on the iodine laser.

A survey of some of the available literature showed a large variation in output mirror reflectivities used. Komarov, Seleznev, and Skorobogatov[9] used a 10% reflecting dielectric; Fuss, Hohla, Volk, and Witte[10] used a 40% reflecting dielectric; and Nordlund[11] used a 60% reflecting mirror. Results published by Aldridge[6] indicate that the optimum reflectivity is above 24%, however, the 80% transmitting dielectric mirror was immediately available and was used for all further testing reported herein. No damage has occured to the dielectric mirror after all subsequent firings.

E. UNCHANGED COMPONENTS

Several components of the previous system were not changed and are being used. The 50KV power supply, four element spark gap and trigger generator are as described by Budzick[12]. The variable reluctance gauge and vacuum systems are as described in Ref. 1.

IV. DISCHARGE DIAGNOSTICS

The investigation of the laser discharge necessitated the use of several diagnostic devices.

The output pulse shapes and durations were obtained using a photovoltaic InSb IR detector manufactured by Barnes Engineering Company connected to a Tetronix 7904 oscilloscope. The oscilloscope was equipped with Polaroid Land Camera permitting photographs of the oscilloscope traces.

The flashlamp output was detected via a Model 330 Photodetector manufactured by Tropel Inc., terminated with 50 ohms.

Energy measurements were taken using a Rk 3230 Energy Meter manufactured by Laser Precision Corporation.

V. LASER PARAMETERS

The following table lists the most important data for the NPS Iodine Laser Oscillator.

Parameter:	Measured Quantity:
Pumped Laser Volume	128.18 cm^3
Charging Voltage	0-25KV
Capacitance	13 microfarads
Flash Duration	30 microseconds
Laser Pulse Duration	10-15 microseconds
Laser Pulse Rise Time	*<200 nanoseconds
Laser Energy Output	0-150 mJ

* Rise time measurement was detector limited.

VI. RESULTS

A. OUTPUT PULSE SHAPE

A typical output pulse for two of the four pressures investigated and 1.3 KJ flashlamp input energy are shown in Figures 1 and 2. The smooth trace is the flashlamp output. The variation in shape with pressure is quite apparent. The 25 Torr pulse, Figure 1, shows a definite build up of the lasing to a peak and then a fall off to a series of small lasing peaks extending for the total duration of the flashlamp output. Whereas the 100 Torr, Figure 2, shows a definite, high onset level and a decay to zero with no trailing peaks as in the 25 Torr case.

The addition of the argon gas as a buffer did not significantly change the pulse shape characteristics. The shape of the pulse appears to be controlled by the total cell pressure rather than the pressure of the iodide gas.

B. LASER ENERGY

The variation of output energy versus C_3F_7I pressure, shot number, and buffer gas was examined. A multitude of problems were encountered at this stage of the investigation. The most troublesome of these problems was the lack of reproducibility of results, the cause of which

was discovered later in the investigation. It was not fully understood at the start of the investigation that the energy output would vary so widely with the shot number, alignment(both detector and laser), and the iodide gas pressure at the low pressures. The deposition of various reaction products from the photolysis on the Brewster windows and laser tube also caused energy variations between fills.

Another prime contributor to non-reproducibility of results was the variable reluctance pressure gauge. The output of this transducer is logarithmic with pressure, the lower pressures(<50 Torr) all are contained between 0.94 and 1.0 volts on the voltmeter. Pressures could only be repeated to within approximately 5 Torr. This was most noticeable at the 25 Torr pressure as is evidenced by the scatter in Figure 9.

The variations were reduced for plotting purposes by the normalization of each output energy run. Each run was normalized using the energy of the first shot as the normalizing factor. This was considered acceptable as it was the rate of deterioration that was of interest at this point not the absolute magnitude of the energy output.

The results obtained in these investigations show a direct correllation with the results published by Fuss and Hohla[13]. It needs to be pointed out that this reference paper was not obtained until after most of the investigations were complete. The variation of laser energy output with shot number is shown in Figures 9 through 14. The increase in deterioration rate with increase in pressure is quite pronounced.

This deterioration as a function of shot number can be described quite closely by a power curve over the first 12

shots. The form of the power curve is

$$y = ax^b$$

The solid curves of Figures 9 through 14 are the power curves computed using a power curve fit routine on a HP-25 calculator. The goodness of fits were all approximately 0.9 or better except for the 25 Torr case. The 25 Torr data suffers from the lack of a reproducible pressure measurement as discussed earlier.

C. BUFFER GAS

The addition of argon as a buffer gas changed the results but not particularly advantageously. The only result reported here is the 50 Torr C_3F_7I plus 50 Torr argon. This data, Figure 13, matches the 100 Torr iodide curve, Figure 11, very closely. This indicates that it was the total cell pressure that was the controlling factor in the rate of deterioration.

D. MOLECULAR IODINE FORMATION

Reference 13 states that:

> "......the energy decrease resulting from repeated shots with the same gas filling of an iodine laser is solely due to an accumulation of I_2 and the consumption of iodide."

The results of the tests on the NPS Iodine Laser support this statement and in addition show that the rate of deterioration is proportional to the total cell pressure. The exponents of the power curve fits range from -0.23 for the 25 Torr case to -0.82 for the 160 Torr case linearly, Figure 15, with total cell pressure. This presents a problem when trying to extract maximum energy from the laser because the deterioration rate increases with pressure as well as available energy[14].

Figure 14 shows the results of a simple test done on the NPS Laser to determine if its energy output deterioration was due to mainly molecular iodine accumulation. A fine copper wire coil, the length of the laser tube, was inserted into the laser tube and a 50 Torr iodide only run was made. The principle was to collect the molecular iodine through chemical reaction with the copper to form cuprous iodide. The marked change in the deterioration curve, Figure 14, is conclusive proof of the deleterious effects of molecular iodine and the value in removing it from the laser system. The formation of the cuprous iodide could be readily seen as a whitish deposit on the copper wire.

The results of the copper wire test altered the direction of the investigation quite drastically. It was felt that the continuation of data gathering for different pump energies and different iodide pressures without at least molecular iodine removal would not be sensible.

VII. RECOMMENDATIONS

There are several changes and/or modifications to the Iodine Laser Oscillator that should be, and in some cases must be, made during the construction of the amplifier stage. These are: (1) Replacement of the existing gas handling system and the construction of the amplifier gas system along the lines recommended in Ref. 13. At a minimum, the new systems should have the capability of molecular iodine removal. (2) Replacement of the existing low voltage portion of the trigger generator with a modern system. This new system should have an expansion capability for future stages. (3) Replacement of the manometer and variable reluctance gauges with suitable pressure gauges. (4) Replacement of the mirrors with dielectric film types specifically coated for the iodine wavelength. (5) Installation of a Pockel's Cell Q-Switch in the oscillator stage.

APPENDIX A

CALIBRATION OF RELUCTANCE TRANSDUCER

1. All valves, Figure 7, closed.
2. Turn on low vacuum system.
3. Connect the mercury manometer as gauge C in Figure 7.
4. Open valves 5,6 and pump down to base pressure.
5. Adjust transducer, gauge B, Figure 7, until a 1 volt deflection is established on the voltmeter.
6. Record the manometer readings.
7. Close valve 5.
8. Using valve 11 to slowly bleed argon into the system, record manometer readings versus voltmeter reading with increasing pressure.
9. Close valve 11 and take another set of readings by lowering the pressure via valve 5 and the high vacuum system.
10. Repeat steps 7,8,9 enough times to establish repeatability of readings.

APPENDIX B

LASER GAS PURIFICATION PROCEDURE

The following procedure should be followed for the initial charging of the system with C_3F_7I. The procedure from step 8 should be followed for a repurification cycle with the system already charged with C_3F_7I. The Veeco Vacuum Gauge tube filaments should be turned off to prevent reaction with the iodine during this procedure.

1. Open valves 1,2,3,5 ,Figure 7, all others closed.
2. Evacuate both gas cylinders to system base pressure.
3. Close valves 1,2, and 3.
4. Open filler cap.
5. Place eyedropper full of C_3F_7I liquid in filler pipe and crack valve 1 momentarily, just enough to draw the liquid into the left hand cylinder, closing valve after each dropper full is drawn in.
6. Repeat step 5 until desired quantity of liquid is in system. 3-4 eyedroppers are sufficient for a large number of fillings of the laser tube.
7. Replace filler cap, ensure valve 1 is closed, open valve 3 and pump the lines down to base pressure.
8. Place dewar around the left hand cylinder and fill

slowly with liquid nitrogen.

9. Wait at least 2 minutes to ensure all C_3F_7I vapour has condensed and the resulting liquid is frozen.

10. Open valve 1 and pump left cylinder out to base pressure ensuring liquid nitrogen in dewar is maintained.

11. Close valve 1 and remove dewar from left cylinder and place slowly around right hand cylinder and refill as necessary to maintain level.

12. Allow left hand cylinder to warm up slighly before starting next step.

13. Using hot water, warm the left hand cylinder to above 40°C.

14. Close valve 3 and open valve 2.

15. Slowly open valve 1 to allow C_3F_7I gas to flow into right hand cylinder and condense. This flow can be detected audibly if one listens carefully. Molecular iodine is removed during this part by the copper screen in the connecting piping.

16. Allow valves 1 and 2 to remain open for a couple of minutes.

17. Close valve 2 and remove dewar of liquid nitrogen from right hand cylinder.

18. Open valve 3 and pump system dowm to base pressure.

19. Repeat another cycle only in the reverse direction so that the iodide gas ends up in the left hand cylinder.

20. The iodine gas now in the left hand cylinder should have most of the impurities removed by this point. It

is recommended that the purification cycle end up with the gas in the left hand cylinder so that it passes through the copper screen as the laser tube is filled.

APPENDIX C

ALIGNMENT PROCEDURE

The following procedure uses two He-Ne alignment lasers to correctly align the NPS Iodine Laser. It is possible to use only one laser but is considered to be far from optimum.

1. Place the pin hole masks on the brewster windows aligning marks on the masks with the marks on the window assemblies.

2. Remove the spherical mirror.

3. Place an alignment laser at A, Figure 16, so that when aligned, its beam passes through both pinholes.

4. Align detectors or any other thing necessary on the alignment laser beam at this time.

5. Place a microscope slide at C, Figure 16, angled to reflect down the returning beam from the planar output mirror.

6. Align the output mirror to reflect the beam back through the pin holes. A spot will be reflected by the slide when the mirror is correctly aligned. DO NOT MOVE LASER A OR MICROSCOPE SLIDE UNTIL INSTRUCTED TO AFTER THIS POINT.

7. Place second laser at B and align its beam through the planar mirror and pinholes. Beam B will partially reflect off microscope slide at C creating a spot at approximately the same position as the spot in step 6.

Minor adjustments to laser B alignment will make the spots coincident. Laser B beam and laser A beam are now parallel and co-axial.

8. Remove laser A and microscope slide at C.

9. Place spherical mirror in place and clamp down.

10. Align spherical mirror to reflect laser B back through pinholes until a spot is formed by reflecting off the microscope slide at D.

11. Remove laser B, microscope slide, and pinhole masks.

APPENDIX D

MAINTAINANCE SCHEDULE

The following steps should be done after approximately 100 firings.

1. Remove the Brewster Windows and clean.

2. Clean the laser tube using stainless steel wire and Kimwipes as swabs.

3. Clean the elements of the spark gap using Kimwipes and ethyl alcohol. Ensure all alcohol vapours are removed form spark gap before firing.

4. Readjust trigger spark visually using screwdriver adjustement. DO NOT PUSH TRIGGER BUTTON WHILE IN CONTACT WITH SCREWDRIVER.

APPENDIX E

SYSTEM OPERATION

The following procedures outline the steps to be taken to bring the laser system up to firing ready, and the securing of the laser system. They assume that the high vacuum system, low vacuum system, reluctance gauge power supply and the associated voltmeter are on and ready. They also assume that the iodide gas is purified and in the left hand cylinder.

A. POWER SUPPLIES

1. Turn on both the trigger generator power and filament switches. After 1 minute the HV ready light will light. DO NOT TURN UP HV AT THIS TIME.
2. Switch on circuit breaker #10, Figure 6.
3. On the lower panel of the 50 KV power supply door, switch on the fan, the rectifier filaments, and the auxiliary power.
4. Ensure HV control variac is at minimum position (fully CCW)
5. Press start button. When system is ready (approx. 2 minutes) the HV READY and MIN SET lights will light
6. Ensure meter-relay pointer set a safe maximum.

7. Press the HV-ON button.

8. Adjust the HV CONTROL variac to the desired voltage.

9. Turn on HV on trigger generator.

10. Adjust variac on lower panel of trigger generator until meter reads 15KV.

11. Adjust potentiometer knob on upper panel until adjacent meter reads 1.1-1.3KV.

12. Check preionizing coils around flashlamps for clearance from high voltage connections.

B. FLASHLAMP FILL PROCEDURE

1. Close valve 5 and open valves 7,8,9 Figure 7.

2. Pump flashlamps down to at least 10^{-5} Torr.

3. Close valve 7 and note manometer reading(gauge A, Figure 7).

4. Open valve 10 slowly and fill flashlamps to the desired pressure.

5. Close valves 8,9,10.

C. LASER TUBE FILL

1. Close valves 4,5.

2. Set reluctance gauge to 1 volt deflection.

3. Open valves 3 and 1 as necessary to adjust voltmeter to desired pressure.

4. Close valves 1,3 and open valve 4. Note drop in pressure.

5. Adjust pressure, using valves 1 and 3, to desired level.

6. If argon is to be added open valves 6 and 11 as needed to introduce the argon.

7. Close valves 1,3,4,(6,11).

8. Ensure filaments are off in the vacuum gauge and open valve 5.

THE SYSTEM IS NOW READY TO FIRE*

D. SYSTEM SECURE

1. Open valve 4 and pump laser tube down to base pressure.

2. Secure the power supplies by reversing their turn on procedures.

APPENDIX F

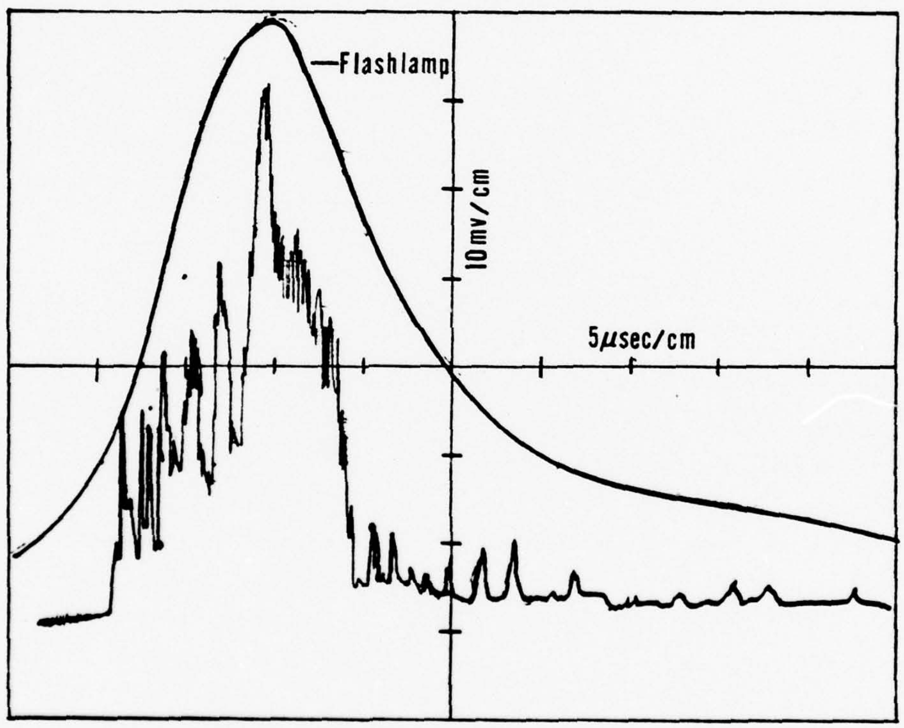


Figure 1 - TYPICAL OUTPUT PULSE (25 TORR IODIDE)

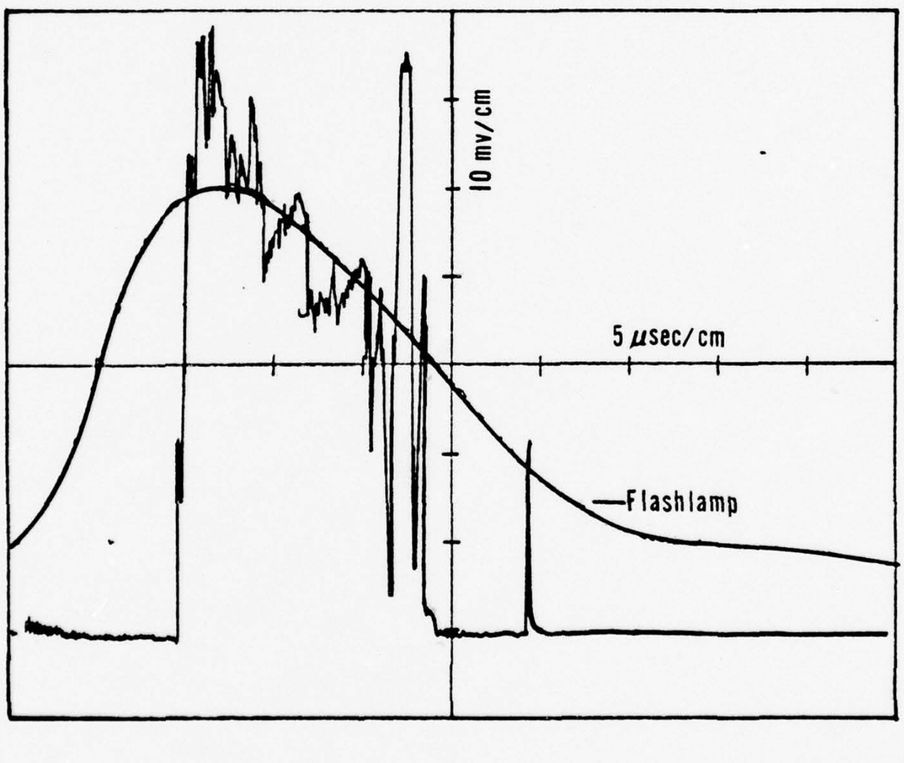


Figure 2 - TYPICAL OUTPUT PULSE (100 TORR IODIDE)

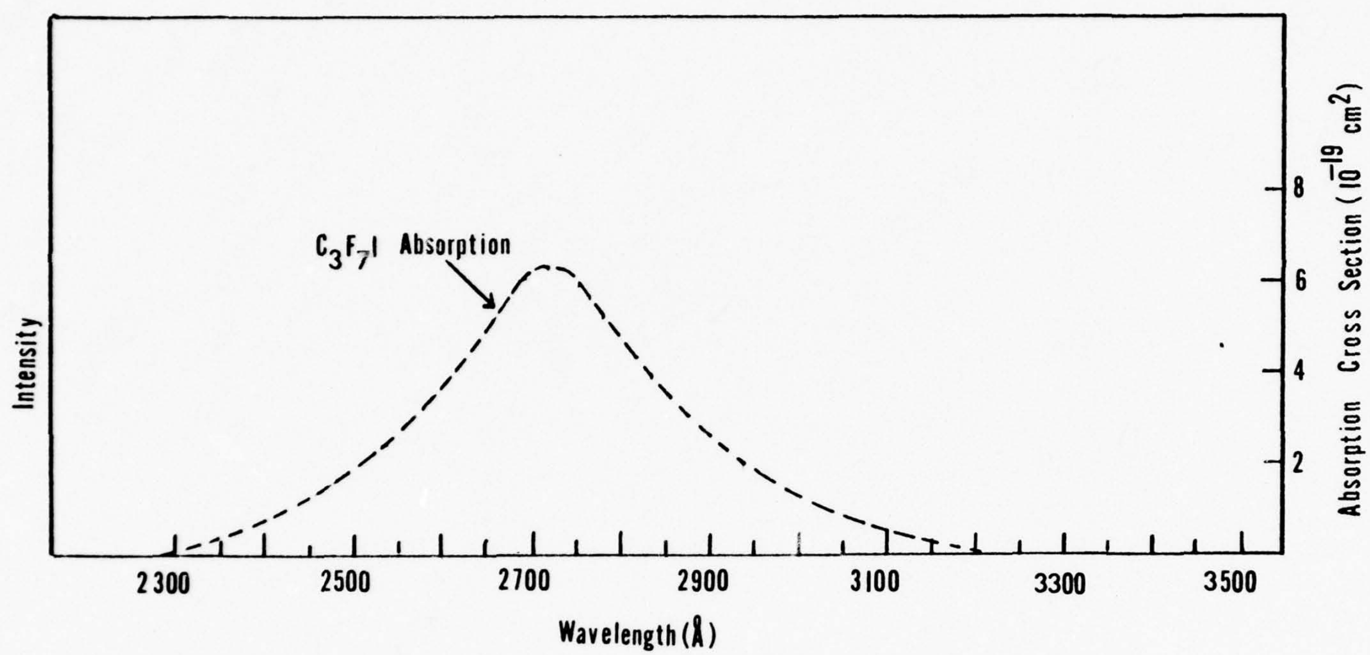


Figure 3 - ABSORPTION SPECTRA

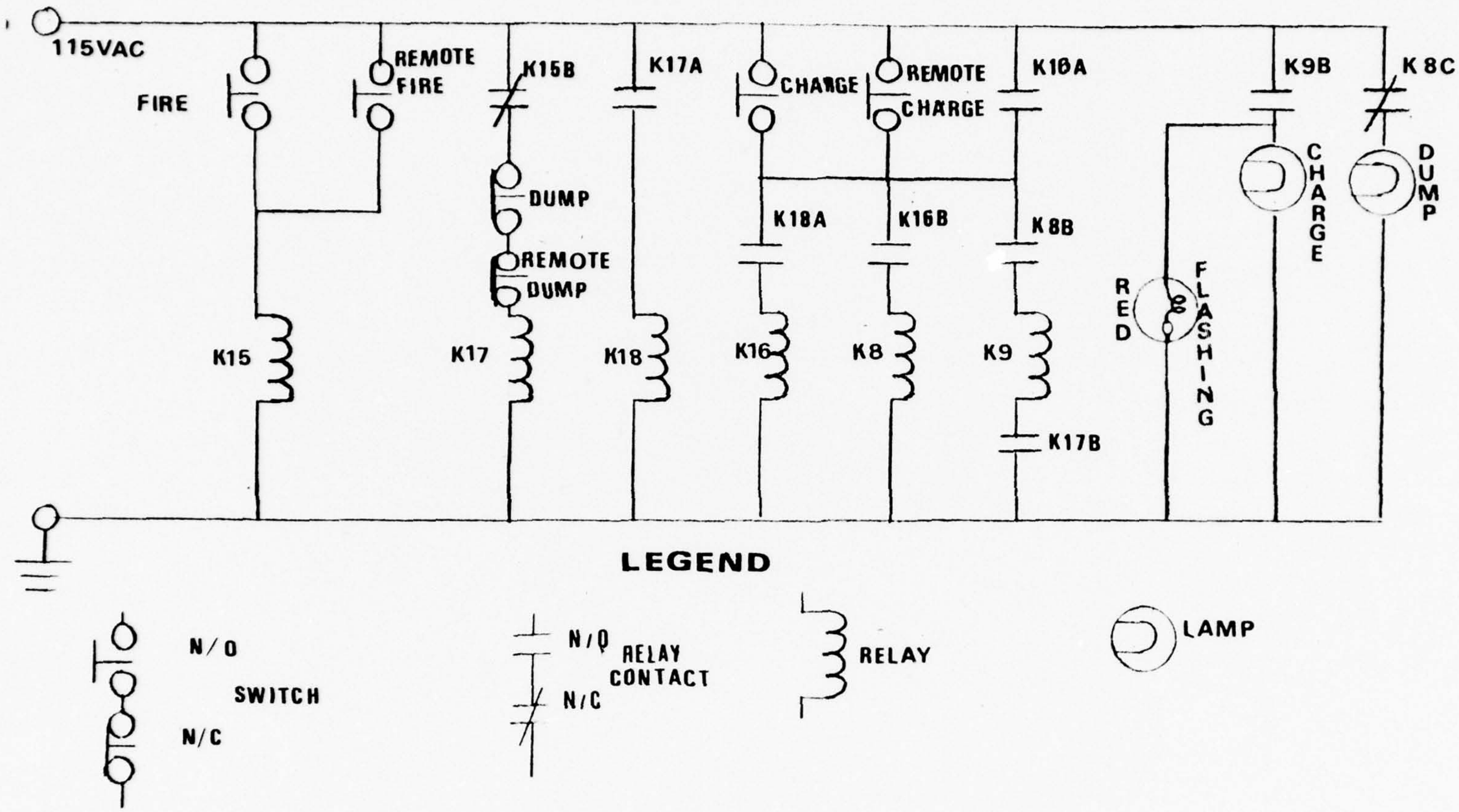


Figure 4 - RELAY LOGIC

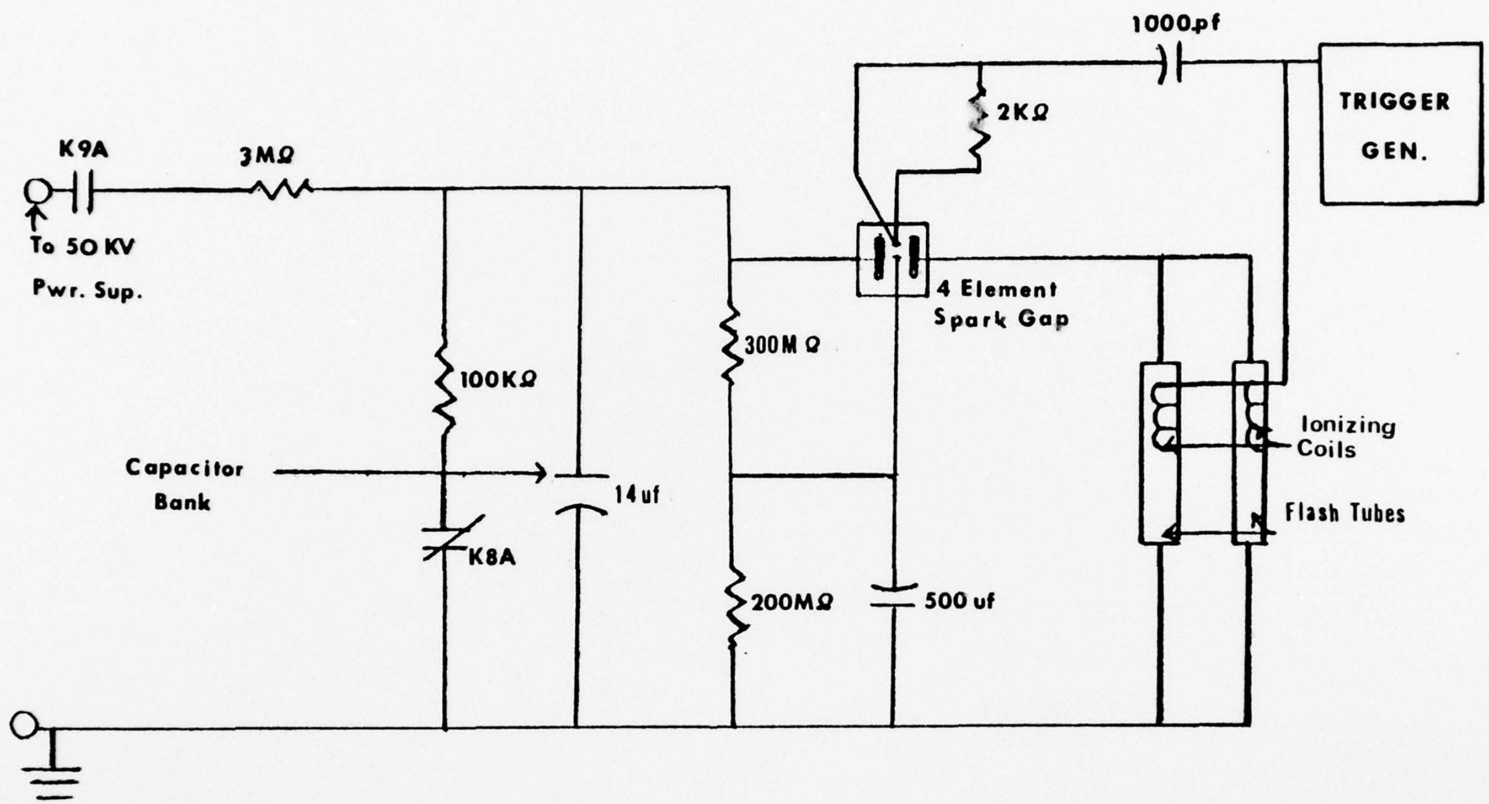
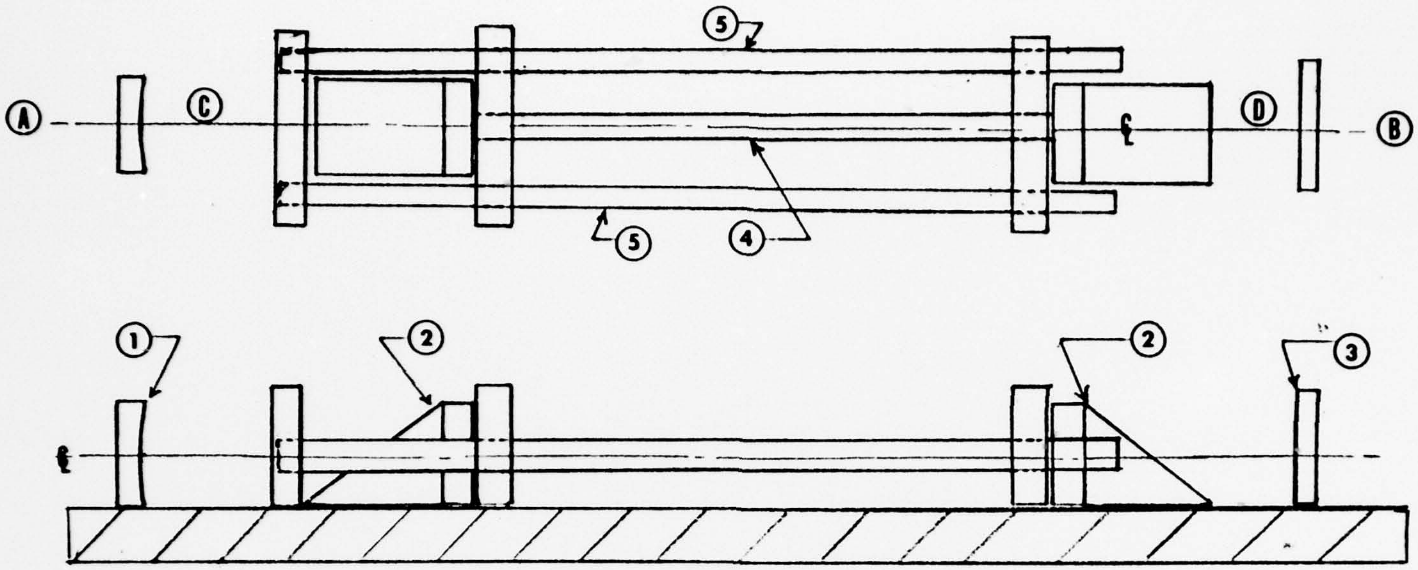


Figure 5 - CAPACITOR CHARGE/DISCHARGE CIRCUITS



1 SPHERICAL MIRROR
2 MONEL LASER HEADS
3 DIELECTRIC FILM MIRROR (PLANAR)
4 SUPRASIL LASER TUBE
5 FLASHLAMPS

Figure 6 - SYSTEM LAYOUT

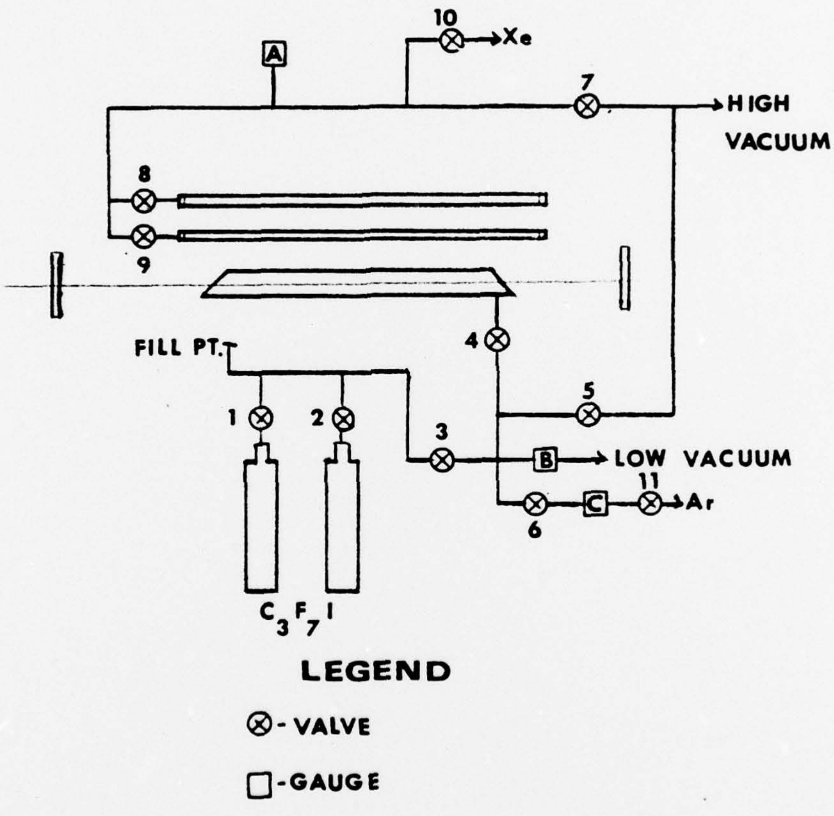


Figure 7 - VACUUM/GAS SYSTEM

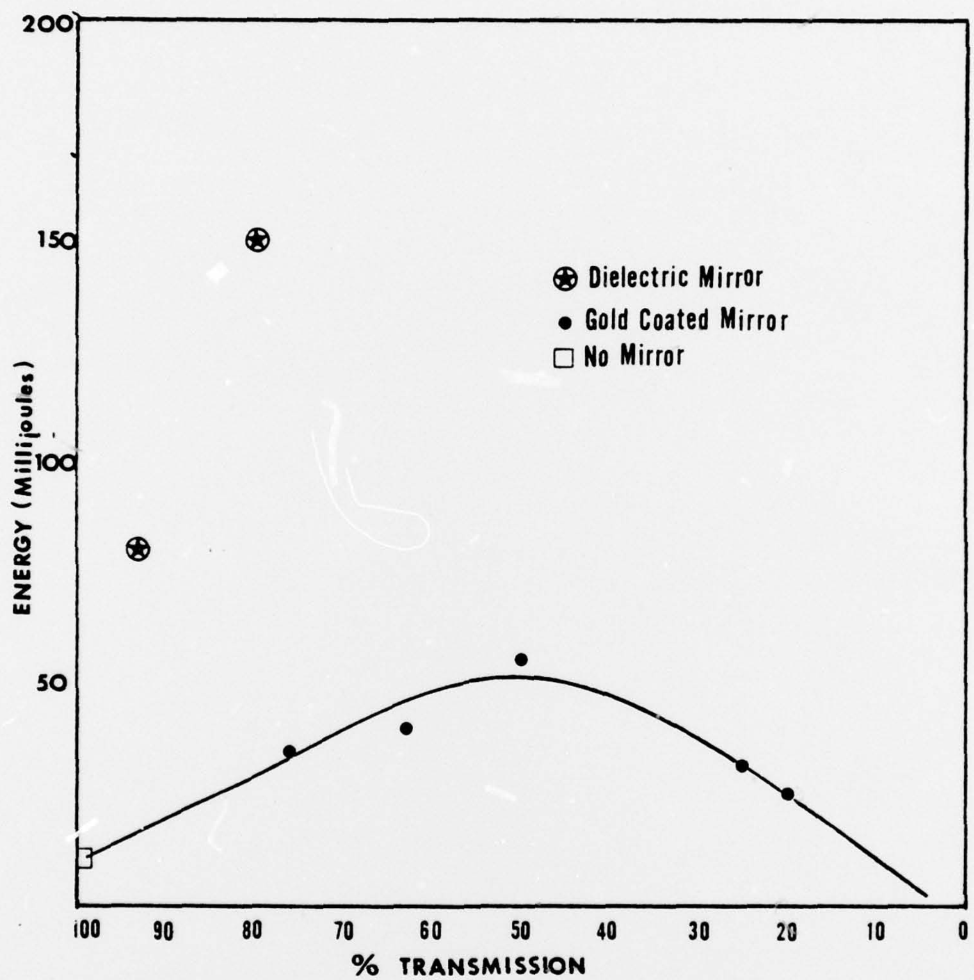


Figure 8 - ENERGY VERSUS TRANSMITTANCE

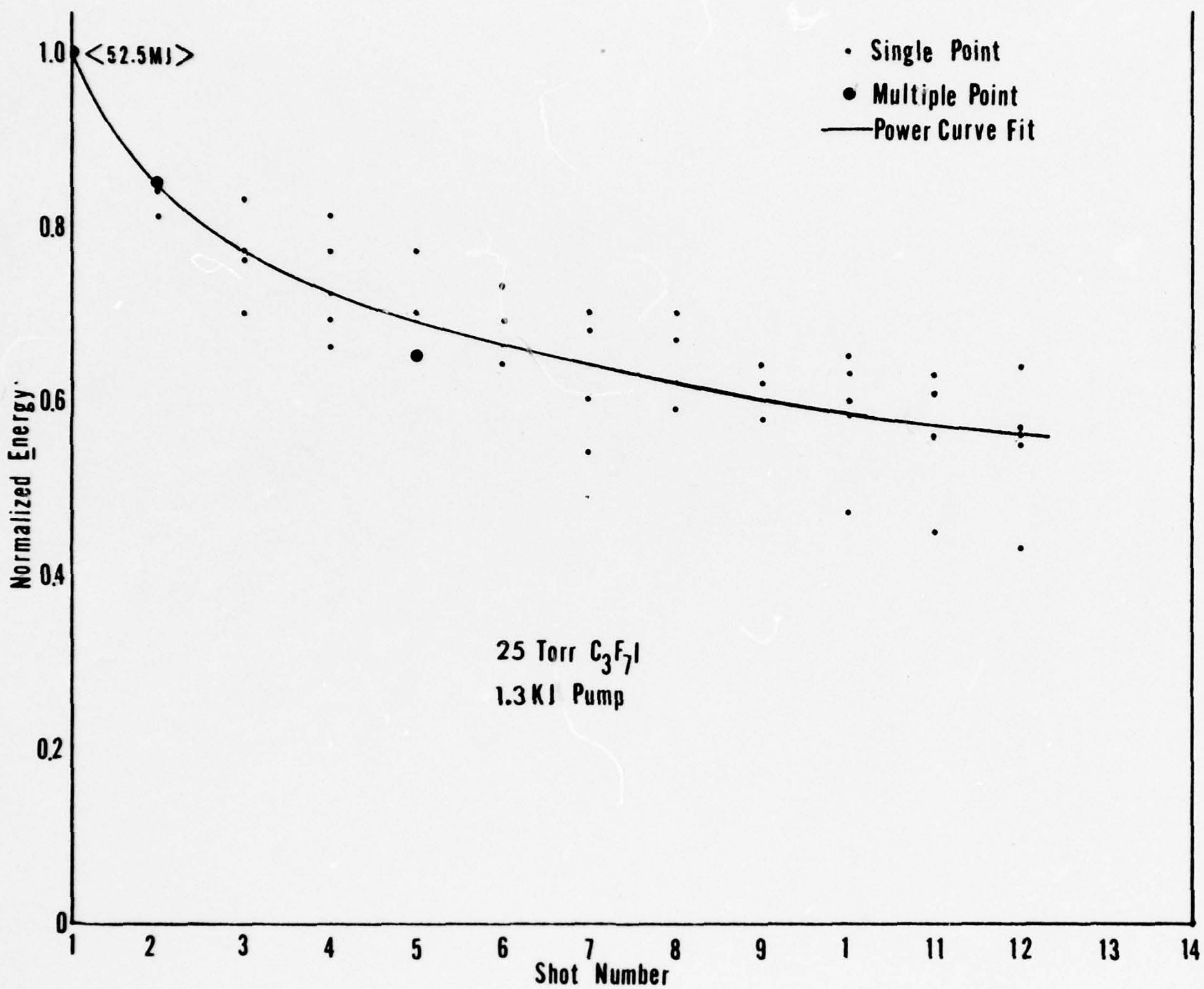


Figure 9 - ENERGY VS SHOT NUMBER (25 TORR)

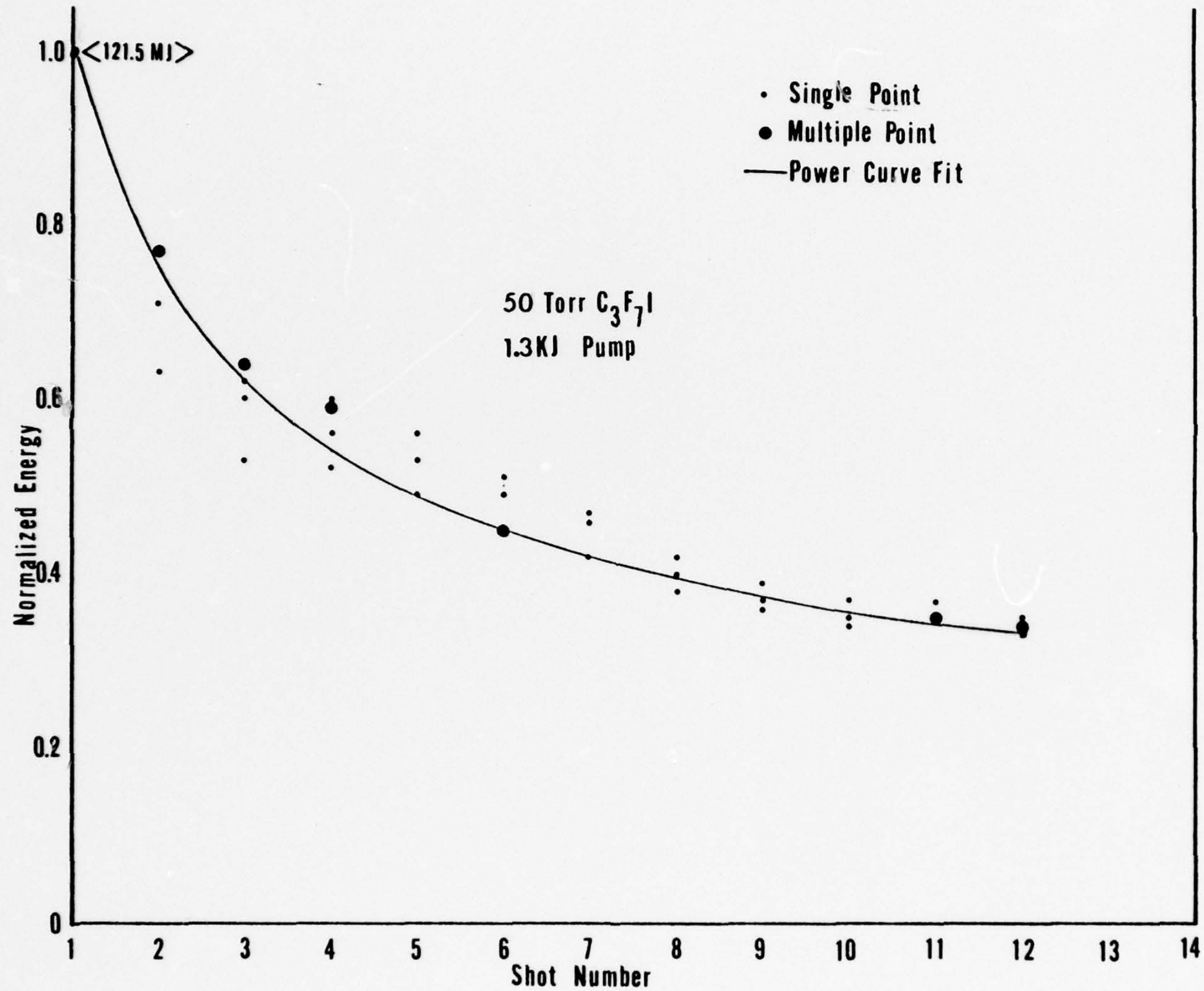


Figure 10 - ENERGY VS SHOT NUMBER (50 TORR)

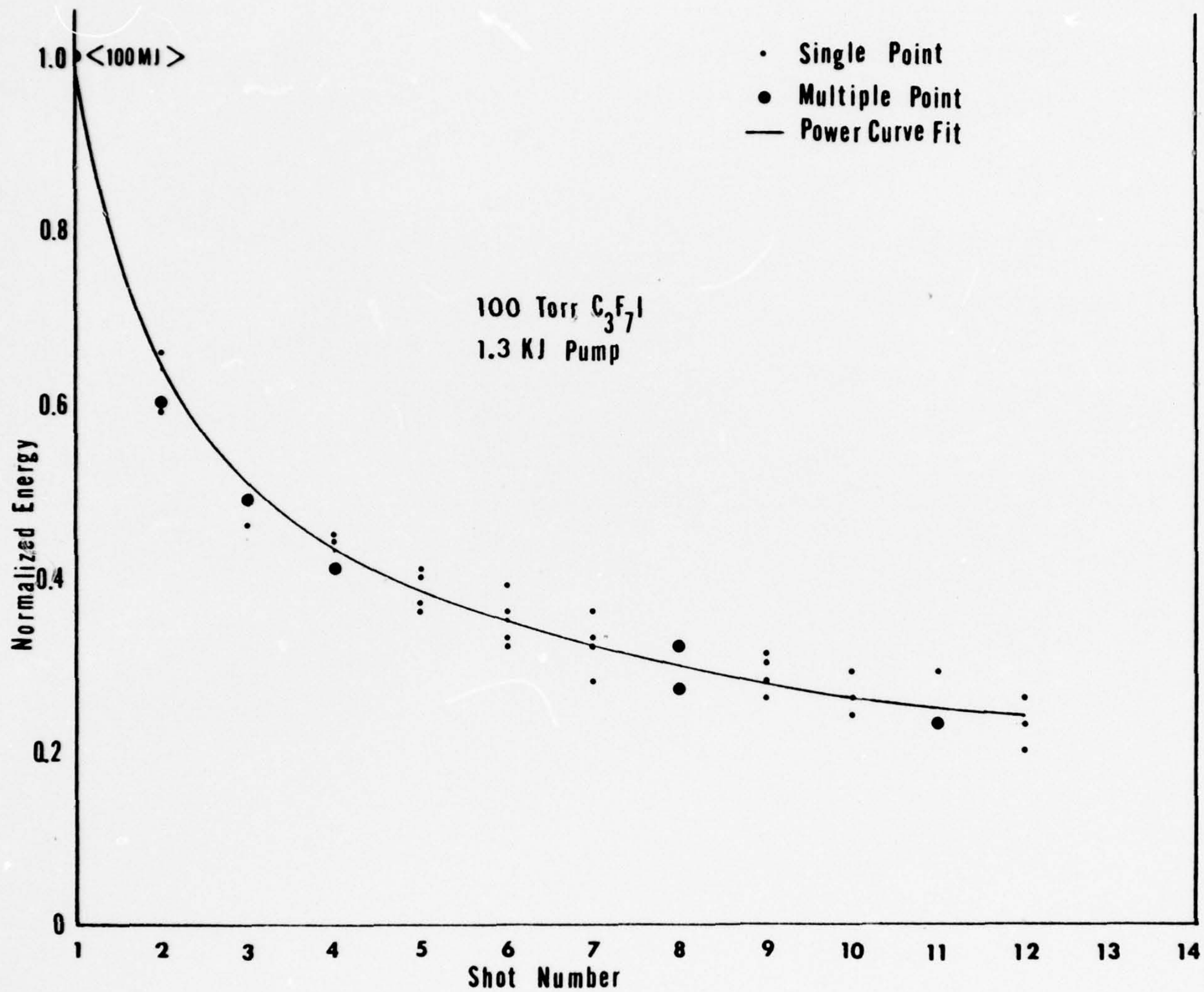


Figure 11 - ENERGY VS SHOT NUMBER (100 TORR)

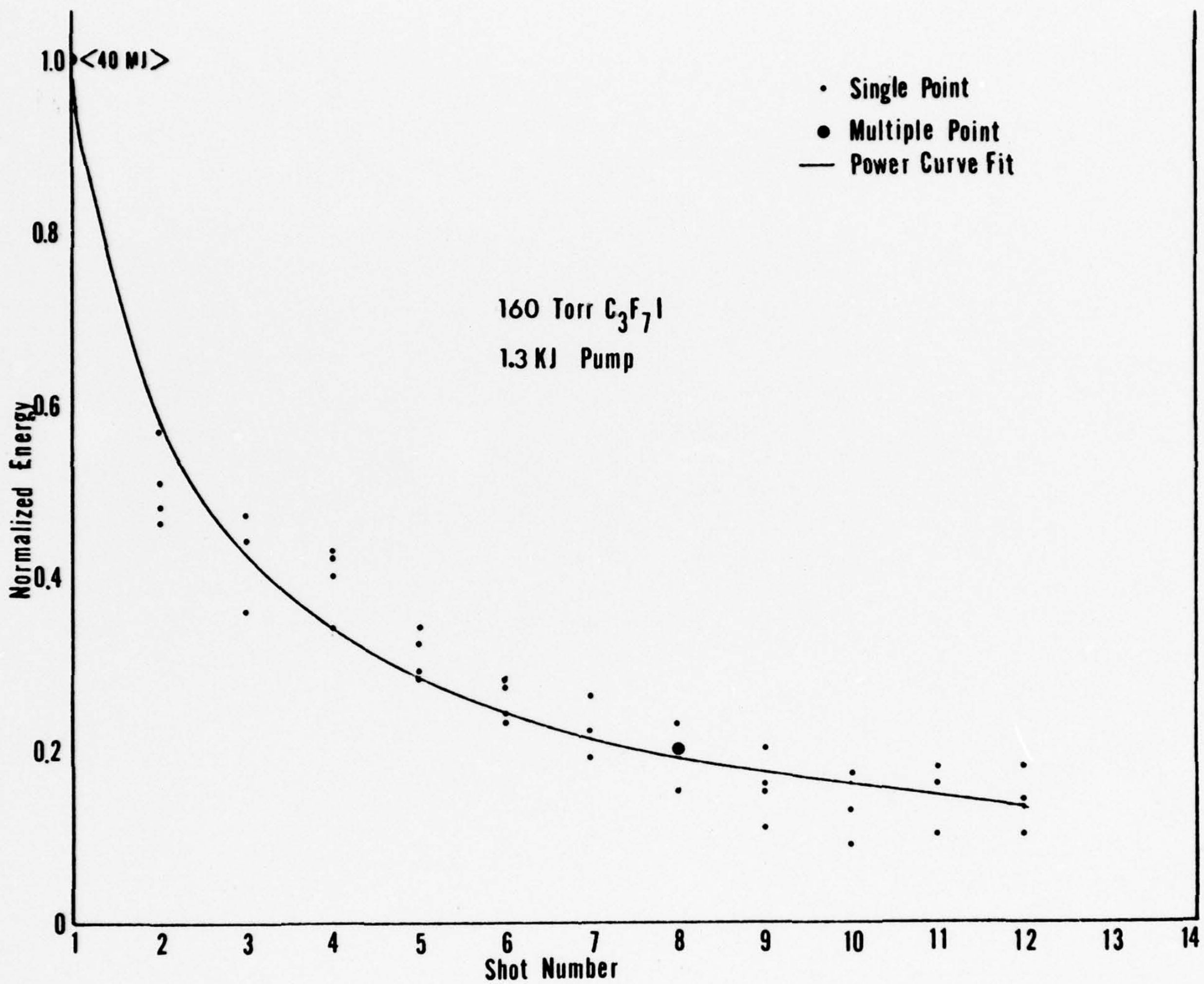


Figure 12 - ENERGY VS SHOT NUMBER (160 TORR)

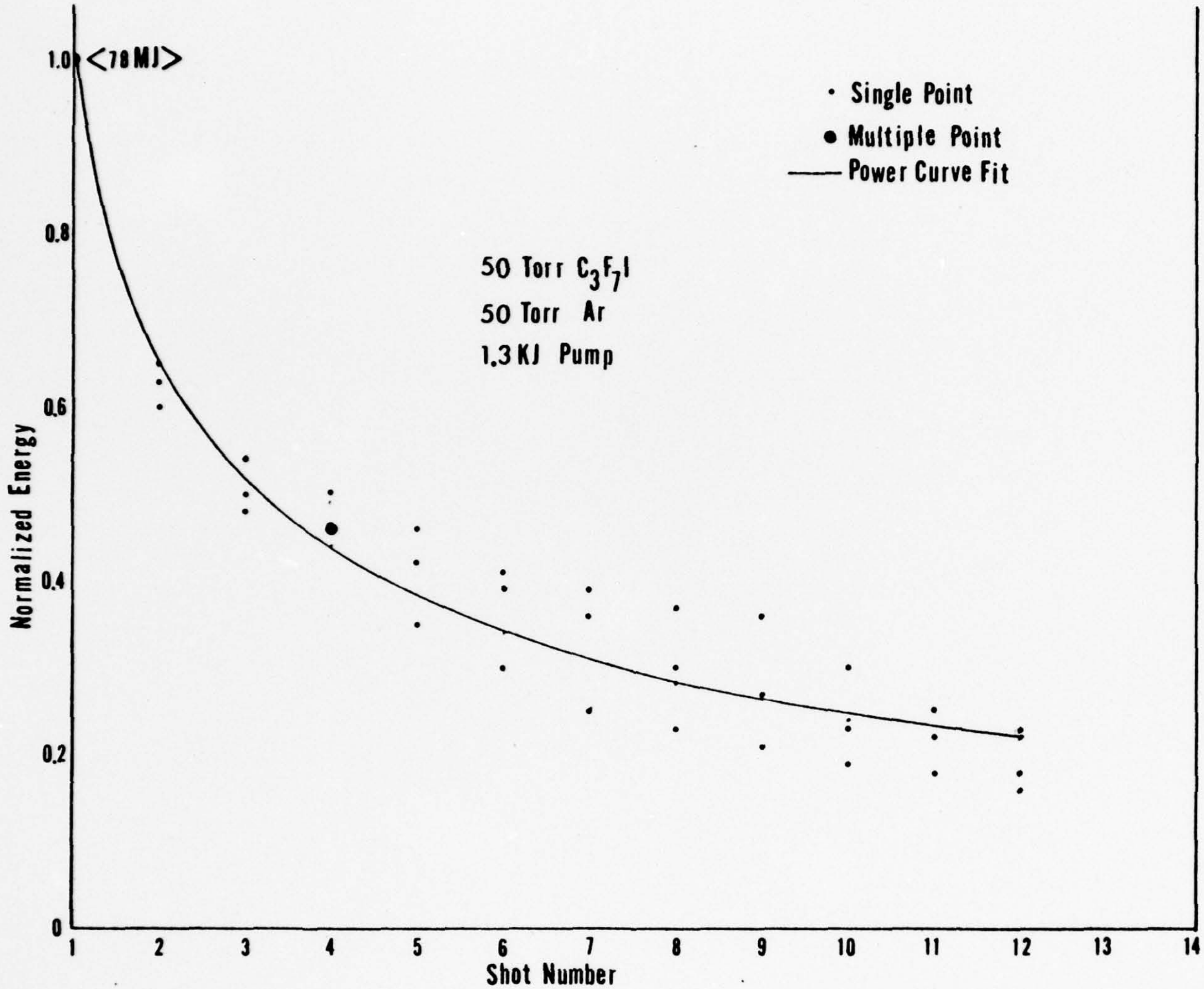


Figure 13 - ENERGY VS SHOT NUMBER (ARGON BUFFERED)

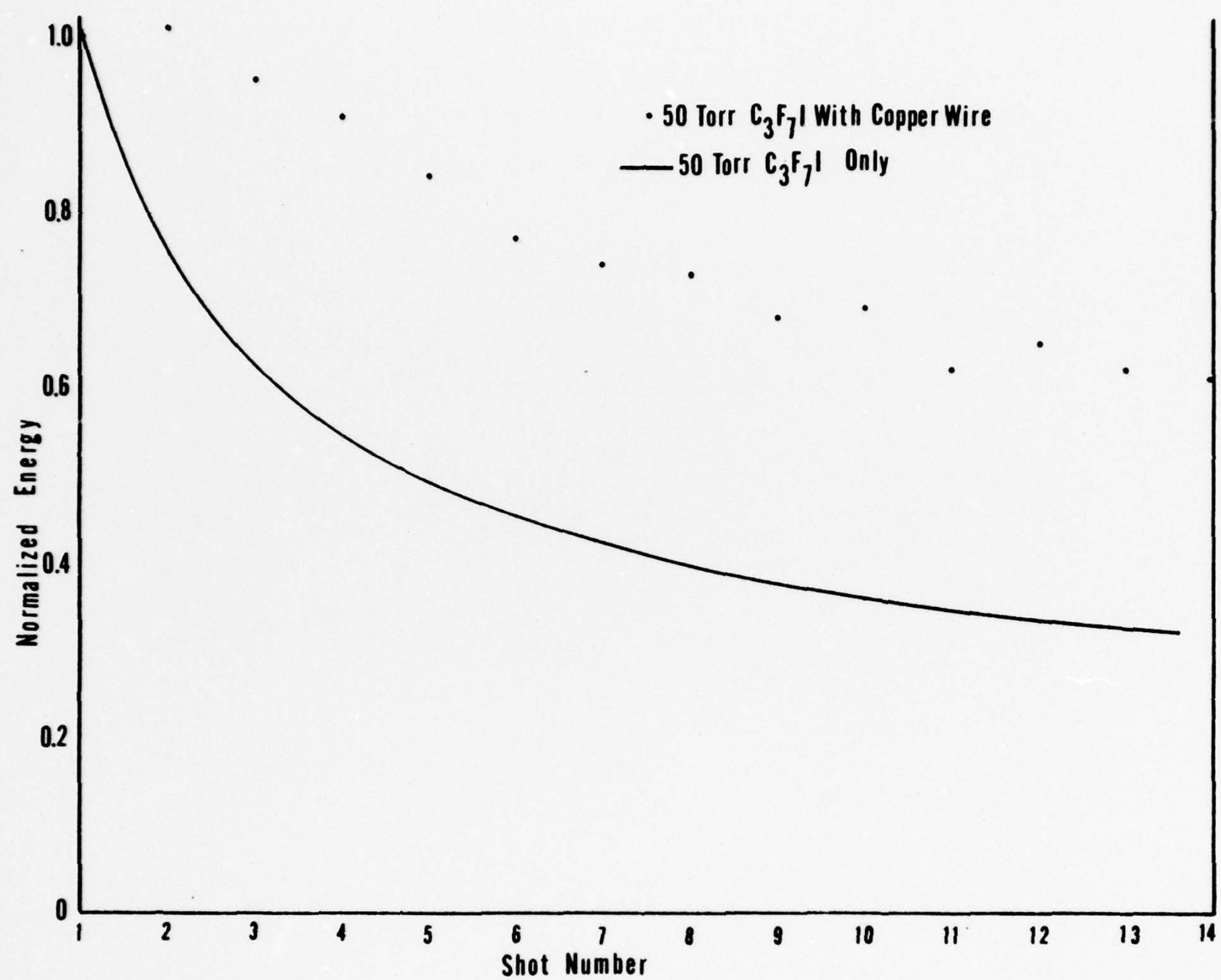


Figure 14 - ENERGY VS SHOT NUMBER (50 TORR WITH PRECIPITATION)

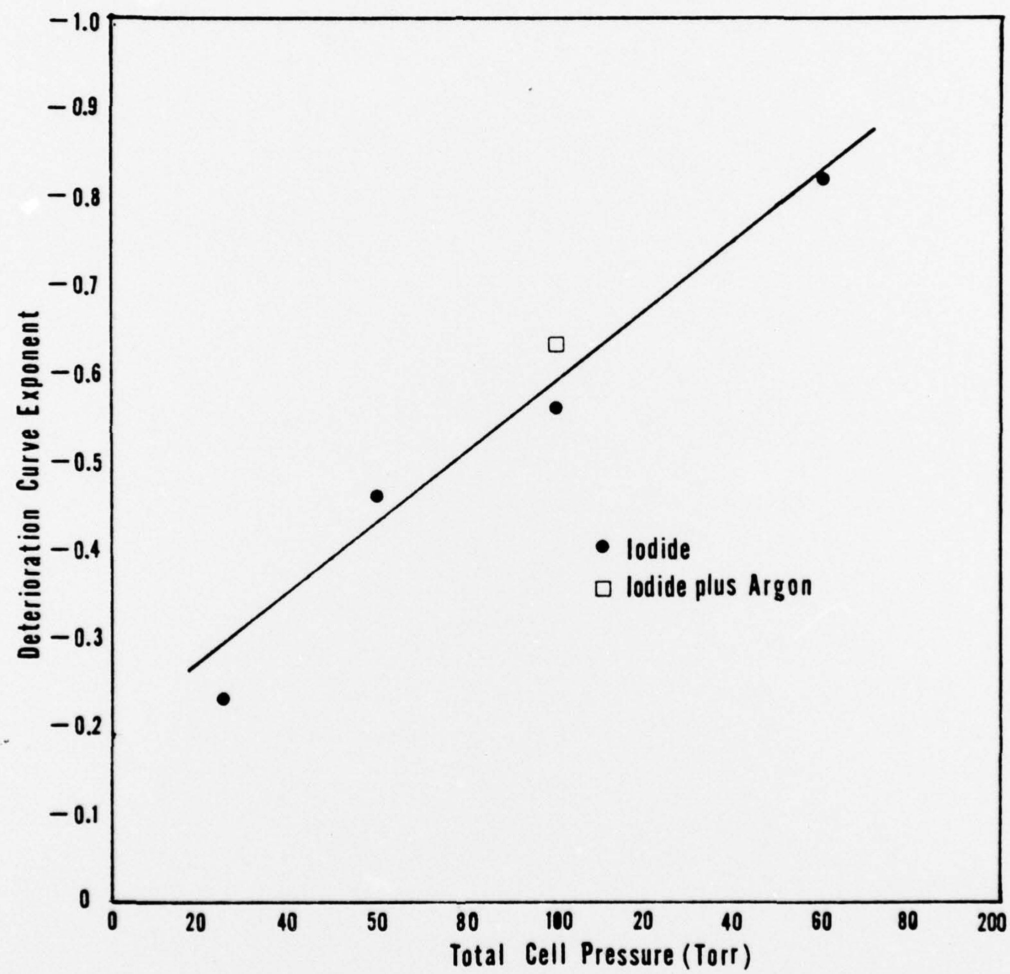


Figure 15 - DETERIORATION EXPONENT VS CELL PRESSURE

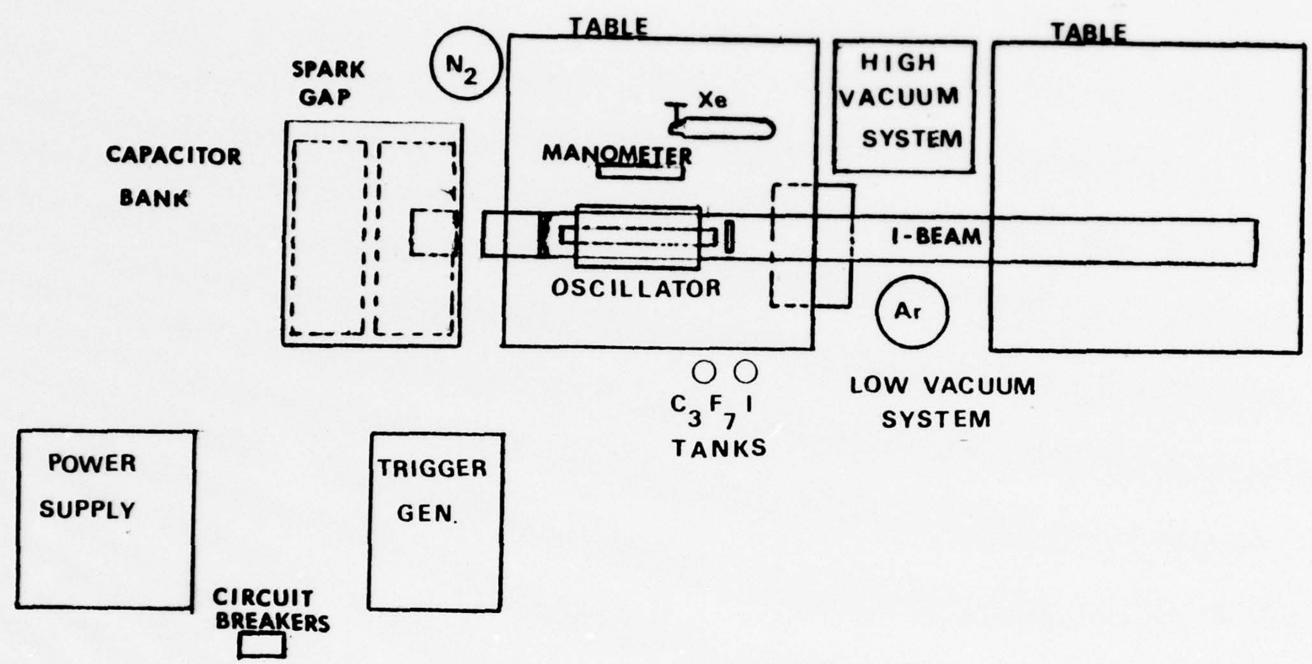


Figure 16 - COMPONENT ORIENTATION

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